PAPER • OPEN ACCESS

Environmental impact of timber frame walls

To cite this article: M Steeman *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012141

View the article online for updates and enhancements.

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012141 doi:10.1088/1755-1315/323/1/012141

Environmental impact of timber frame walls

Steeman M[1], Himpe E[1], Vanroelen M[1], De Roeck M[1]

[1]Ghent University, Building physics research group

Marijke.Steeman@UGent.be

Abstract. Timber frame walls are increasingly applied nowadays due to the stringent energy performance requirements of buildings. The aim of this study was to investigate the environmental impact of this type of construction. Therefore, a cradle to gate analysis was used. The study consists of three consecutive steps. First the impact of the constituting materials was studied. The results show e.g. that the environmental impact of LVL studs is significantly larger than that of SLS studs or I-joists. Based on these results on material level, in the second stage three timber frame walls were designed and evaluated. All walls had the same thermal performance. When comparing the results, it was noted that the environmental impact of the wall with the highest impact is three times larger than that of the wall with the lowest impact. Finally, the study also looked at the additional impact of tapes for guaranteeing the air tightness of timber frame constructions and at the impact of fasteners. It could be concluded that the impact of tapes is negligible when looking at the total impact of the wall (less than 1%). The fasteners on the other hand, lead to an increase in environmental impact with almost 20%.

1. Introduction

Buildings have a large impact on our environment: 25% of the total primary energy use is related to the use of buildings while 40% of the CO_2-emissions are generated by fossil fuels used in buildings. On the other hand, a large amount of energy is embodied in the building materials. Studies show that in a typical Belgian dwelling 10 to 30% of the total environmental impact is caused by the building materials [1]. As the energy performance of buildings increases, the relative impact of the building materials will rise due to the lower operational energy use at the one hand and the larger amount of materials (i.e. insulation materials) on the other hand. Therefore it is important to gain insight in the environmental impact of construction elements.

As the energy regulations move the construction sector towards thicker insulation layers, timber frame construction elements become in favour. Figures show that in the past years timber frame is used more frequently. In 2011, in 5,9% of the new Belgian dwellings timber frame construction was used. In 2016 this figure was almost doubled (9,3%). It is expected that this number will further increase to 15 to 20% in 2020 [2].

Therefore the aim of this work is to gain insight in the environmental impact of timber frame walls. In a first step the environmental impact of the constituting building materials is studied. Based on these results on material level, in the second stage three timber frame walls were designed and evaluated. Finally, the influence of fasteners and air tight tapes on the total environmental impact is investigated.

2. Methodology

The analysis is carried out in Simapro version 8.4.0.0 with the Swiss Ecoinvent database v3.3 [3]. As many building materials that are used in Belgium are in whole or in part produced in Europe, the

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012141 doi:10.1088/1755-1315/323/1/012141

European context is a good estimation for the Belgian context. Moreover, it is shown that the European electricity mix is a good assumption for the Belgian electricity mix [4].
Furthermore the allocation default model in Simapro is used. The building materials considered in this analysis are mainly primary materials. This means that materials do not consist of recycled or reused materials. In that way allocation is avoided.

The ReCiPe end point (h) method is used. The study includes a cradle to gate analysis, meaning the operational phase and the end-of-life phase are excluded from the analysis. Hence mining, production of materials and transport of materials to the building site are considered.

During forest growth CO_2 is captured in wood. This energy is released during wood incineration. When however, different life cycle phases are split up and the embodied energy in timber construction is analysed, the initial energy is of no interest because it is not related to production or transportation. When on the other hand, wood is used as a fuel (biomass), it is important to include the initial embodied energy [4]. Consequently, for this study the initial energy is not included in the analysis.

In the analysis replacements are only taken into account for finishing materials when looking at the environmental impact of the timber frame wall. It is expected that construction materials such as sheathing boards will not be replaced during the life span of the timber frame construction (60 years). The life span of the building materials that are used in timber frame construction is based on [4].

3. Impact analysis of constituting materials

The constituting materials are divided according to their functionality: structural elements, thermal insulation material, interior sheathing board, exterior sheathing board, interior finishing boards and exterior finishing materials.

3.1. Structural elements

Three types of structural materials are considered: I-joists, laminated veneer lumber (LVL) beams and massive spruce studs (SLS) The functional unit is the material that is needed for a structural part of 1 m^2 of timber frame wall of a typical single family dwelling with three floors. The wall has a heart to heart distance of 40 cm, which is typical for this type of construction. This results in three vertical studs per functional unit. Table 1 shows the material volumes that were taken into account. The life span of all structural elements is 60 years [4].

Table 1. Material data for timber frame structures

Category	**Materials**	**Dimensions (mm)**	**Volume (m^3)**
SLS	Sawnwood	45x184	0,025
LVL	Laminated timber	45x200	0,027
I-joist (45x200)	Sawnwood (web)	45x45	0,012
	Fibreboard (flanges)	6x126	0,002

Figure 1a shows the impact of the wood structure included in $1m^2$ of timber frame wall. As wood is used as a structural element, the impact on Land use is significant, which leads to a higher score on the Ecosystems category compared to Human Health (HH) or Resources. When comparing the three types of structural elements, it is noted that the impact of the LVL studs is larger than that of SLS or I-joists. Two explanations can be found: when applying LVL studs a larger material volume is used. On the other hand the material is used less efficient: to produce $0,027m^3$ laminated wood $0,053m^3$ softwood is necessary, while less is necessary to produce SLS studs. The I-joist clearly has the lowest impact in the Ecosystems category which is due to the lower amount of wood used. Furthermore the use of synthetic resin in LVL studs generates a high impact on HH and Resources. This is also the reason why I-joists have a slightly higher impact than SLS in these categories.

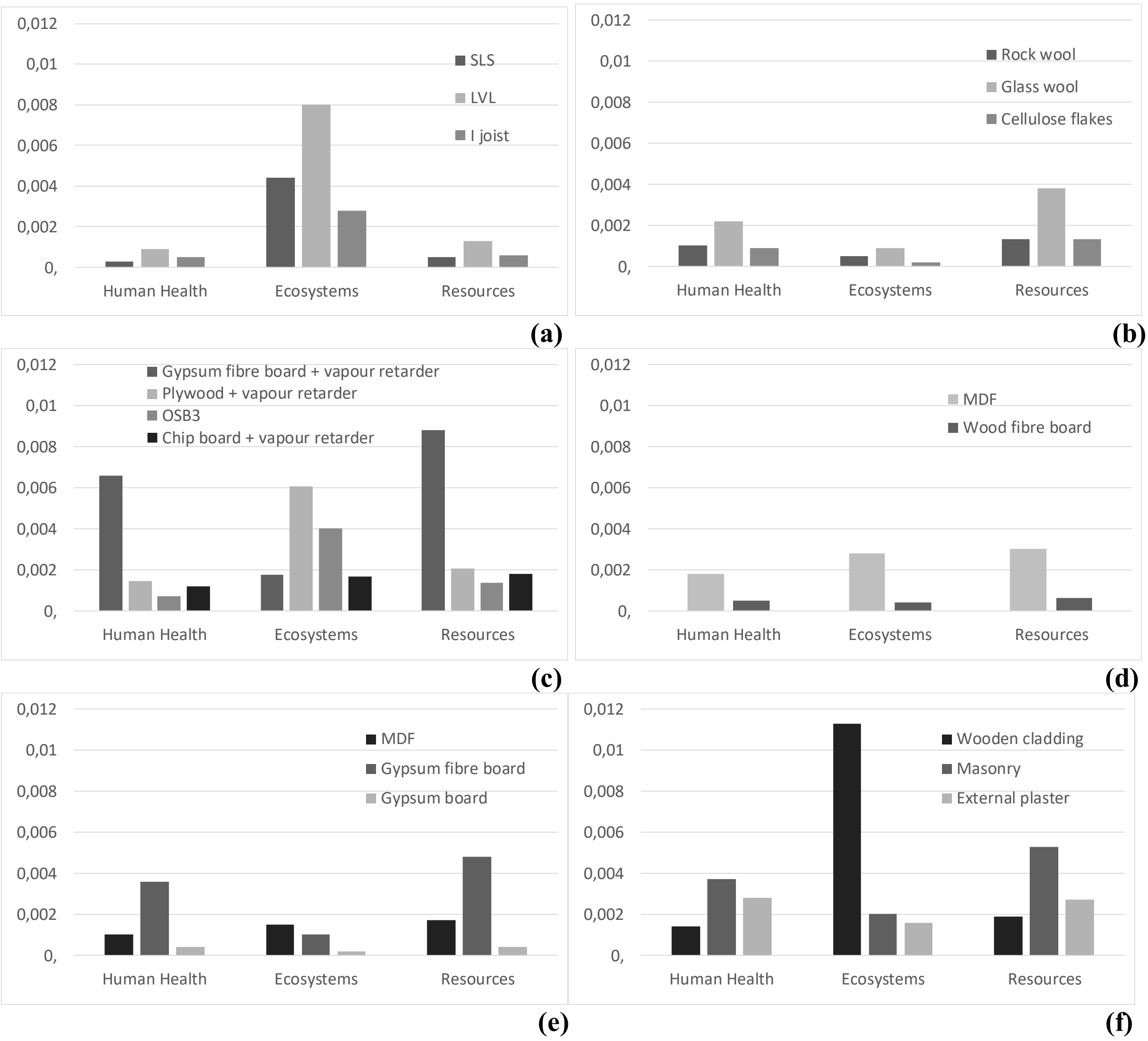

Figure 1. Normalized impact of wood frame structure (a) ; insulation material (b) ; interior sheathing board (c) ; exterior sheathing board (d); interior finishing boards (e) and exterior finishing materials (f)

3.2. Thermal insulation

Next, the environmental impact of three types of insulation material that are typically used in timber frame construction is evaluated: cellulose flakes, glass wool and rock wool. The functional unit is 1 m² of material with a heat resistance R_c of 4,17 m²K/W. This corresponds to a U-value of about 0,24 W/m²K which is a requirement for new walls in Belgium. Life span of insulation materials is 50 years [4].

Table 2. Material data for thermal insulation materials

Category	Thermal conductivity (W/mK)	Layer thickness corresponding with R_c = 4,17 m²K/W	Density (kg/m³)	Mass for 1m² wall (kg)
Cellulose flakes	0,040	0,167	50	8,33
Glass wool	0,039	0,163	40	6,50
Rock wool	0,035	0,146	45	6,56

Figure 1b shows that glass wool generates the highest impact, while cellulose flakes have the lowest impact. The production process of glass wool is energy-intensive, explaining the high impact on Resources. Furthermore polymerised synthetic resin based on urea is used during production, having an impact on HH. Cellulose flakes are produced from recycled newspaper. The impact on HH and Resources is due to the use of zinc during the production process where it is used for a better bond between the paper fibres and the boron salts.

3.3. Interior sheathing board

The impact of four types of interior sheathing board is compared: gypsum fibreboard, plywood, oriented strand board (OSB) and chipboard. All boards have a comparable thickness, representative for a typical thickness that is available on the market (Table 3). The functional unit is 1 m². In order to take exclude the risk of interstitial condensation in the timber frame elements, an additional vapour barrier is added for all sheathing boards except OSB. The life span of all sheathing boards is 50 years [4].

Table 3. Material data for interior sheathing boards and vapour retarder

Category	Thickness (m)	Density (kg/m³)	Mass (kg)	Volume (m³)
Gypsum fibreboard	0,018	1150 kg/m³	20,7 kg	-
Plywood	0,019	650 kg/m³	-	0,019
OSB3	0,018	600 kg/m³	-	0,018
Chipboard	0,019	680 kg/m³	-	0,019
Vapour retarder (PE film)	0,0002	-	0,188	-

Figure 1c shows the results. Gypsum fibre board has the highest impact on HH and Resources. This is explained by the use of zinc during production. The impact of the other sheathing boards is lower for these categories, and largely determined by the amount of binder that is used for compressing the wood into a plate material. The impact on Ecosystems varies for all sheathing boards and is the highest for plywood. This can be explained by the amount of wood used during production. E.g. in the production of chip boards a large amount wood residues are used, resulting in a relatively low impact on this category. Furthermore, the impact of the vapour retarder showed to be negligible [6].

3.4. Exterior sheathing board

The impact of wood fibre board (WFB) is compared with the impact of medium density fibre board (MDF). Both boards have a thickness of 0,018 m, which is a typical thickness available on the market. The functional unit is 1 m². The life span of the sheathing boards is 50 years [4].

Table 4. Material data for exterior sheathing boards

Category	Thickness (m)	Volume (m³)
WFB	0,018	0,018
MDF	0,018	0,018

Results can be found in Figure 1d. A large difference between MDF and WFB is observed. Though the impact of MDF is on average lower than the impact of other sheathing boards as shown in Figure 1c, it is clearly higher than the impact of WFB. The low impact of WFB is explained by the use of wood residues from saw mills (low impact on Ecosystems) and the use of lignin as a natural binder instead of synthetic resin glues during production (positive effect on HH and Resources).

3.5. Interior finishing boards

Gypsum fibre board, MDF and gypsum board (also known as plaster board) are commonly used as an interior finishing board. Once again, materials with a typical thickness available on the market are considered. The functional unit is 1 m², the life span of these materials is 50 years [4].

Table 5. Material data for interior finishing boards

Category	Thickness (m)	Density (kg/m³)	Mass (kg)

Gypsum board	0,0095	810,5	7,7
Gypsum fibre board	0,010	1150	11,5
MDF	0,010	760	7,6

Results can be found in Figure 1e. The impact of gypsum fibre bard and MDF was already discussed in Figures 1c and 1d. Note that the impact of MDF used as an interior finishing board is lower than when used as an exterior sheathing board due to its reduced thickness.

Figure 1e shows that the impact of gypsum board is the lowest for all categories. The gypsum used in the production of gypsum boards either is a natural product or it is originated from flue-gas desulfurization of brown coal power plants, explaining its low environmental impact. The production also requires zinc, which results in a higher impact on HH and Resources. Gypsum fibre board generates the highest impact of all three materials.

3.6. Exterior finishing materials

Three types of exterior finishing layers are considered: bricks, external plaster and wooden cladding. The material thicknesses that are considered in table 6 are based on a correct technical design. E.g. for the wooden cladding, vertical wooden battens (30 x 24 mm) are used, with a heart to heart distance of 60 cm. Hence, two vertical battens per functional unit of 1 m² of finishing layer are taken into account.

Note that the life span of the finishing materials differ: for masonry, external plaster and wooden cladding the life span is respectively 80, 15 and 30 years [4]. This means that for the external plaster and the wooden cladding replacement of materials has to be taken into account. During a life span of 60 years the plaster layer will be replaced 4 times, while the wooden cladding requires one replacement.

Table 6. Material data of exterior finishing materials

Category	Components	Density (kg/m³)	Thickness (m)	Mass (kg)	Volume (m³)
Masonry	Bricks	1900	0,075	116,15	-
	Mortar	1800	-	5,31	-
External (mineral) plaster	Fiberglass reinforcement	-	-	0,44	-
	Plaster	1700	0,015	99,20	-
Wooden cladding	Vertical wooden battens	450	0,030	-	0,0029
	Horizontal wooden boarding	600	0,018	-	2

Figure 1f shows the results of the impact analysis. The outlier in the Ecosystems category pops out immediately: the use of wood generates a large impact on Ecosystems. On the other hand, the impact of wooden cladding on the HH and Resources is relatively limited.

The impact of the brickwork is determined by the ceramic stones, the influence of the mortar in the joints is rather limited. The material mainly has an impact on Resources: on the one hand this is due to the high energy use in the burning of ceramic bricks requiring fossil fuels, on the other hand it can be explained by the exhaustion of mineral resources used for the production of ceramics.

The main resources needed for the production of mineral plaster are sand and cement. While sand is a natural product, the use of cement generates a high impact because of the high temperatures in the production process, causing a high energy demand. Because of the replacement during the total life span, the overall impact of plaster becomes larger. Due to this, the impact of plaster will be higher on HH and Resources than that of a wooden cladding.

When considering all three categories, from an environmental point of view the mineral plaster is favourable over the masonry façade and the wooden cladding.

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012141 doi:10.1088/1755-1315/323/1/012141

4. Impact variation of timber frame walls

Based on the previous results on material level, in a second step the constituting materials are combined in three timber frame wall designs. Care is taken that the construction is correct from a hygrothermal point of view. All walls have a similar thermal transmittance U of 0,22 W/m²K.

Figure 2 shows the wall constructions: the first timber frame wall is constituted from materials with an overall low impact (“low impact wall”), while the constituting materials with an overall high impact are used in the “high impact wall”. Finally the environmental impact of these wall types is compared with that of a typical timber frame wall design used in Belgium.

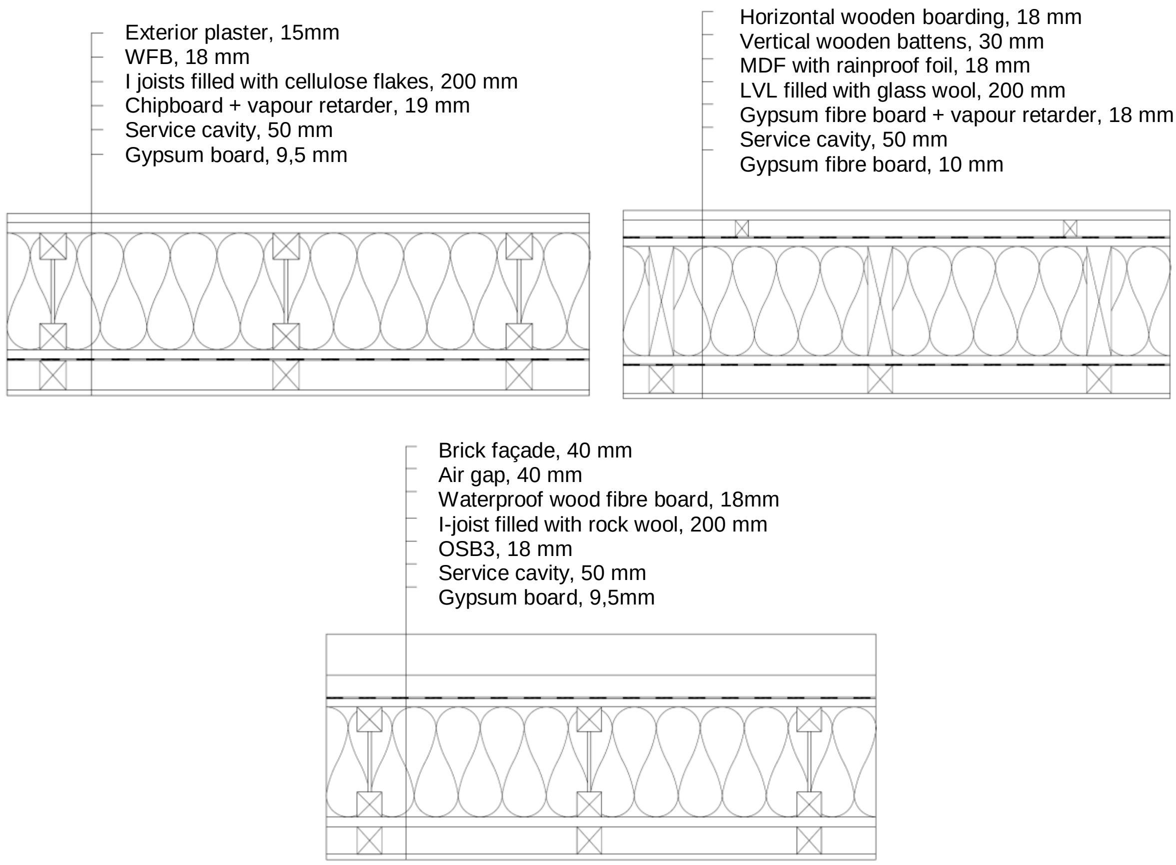

Figure 2. Low impact wall (upper left), high impact wall (upper right) and typical Belgian timber frame wall construction (below)

Figure 3 shows the environmental impact of the three wall types. It can be seen that the impact of the low impact wall is about three times lower than that of the high impact wall, for each of the impact categories. Furthermore it can be observed that the impact of the typical timber frame construction is more leaning towards the low impact wall: the impact on HH and Resources is comparable (slightly higher), while the impact on Ecosystems is about 25% higher.

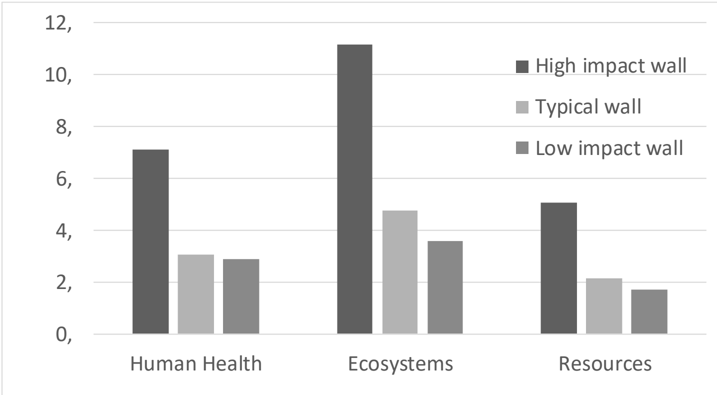

Figure 3. Impact variation between timber frame wall constructions

5. Impact of fasteners and tapes

In a last step the impact of fasteners and tapes that are necessary to guarantee the airtightness of a timber frame wall are included in the impact analysis. The impact analysis is based on the typical timber frame construction shown in figures 2 and 3. In order to evaluate the environmental impact a wall with and without fasteners and tapes is compared. A timber frame wall of 3 m length and 2,44 m height is considered (total area of 7,32m²). Taking into account a heart to heart distance of 40 cm, the timber frame wall consists of 8 vertical studs.

Following fasteners are included in the wall, based on typical practice:

- Cavity anchors: 4 per m² of brick façade
- Staples to fasten WFB (dimensions 600 mm width x 2500 mm height), spacing 100 mm
- Staples to fasten OSB3 (dimensions 600 mm width x 2440 mm height), spacing 100 mm
- Screws to fasten gypsum board (dimensions 1200 mm width x 2600 mm height), spacing 200 mm

The boards are cut to a height of 2,44 m and to the width between two vertical studs (40 cm). The amount of fasteners and their total mass can be found in Table 7. All fasteners are made of stainless steel (density 7930 kg/m³).

Table 7. Fasteners

Category	Number	Length (m)	Diameter (m)	Volume (m³)	Mass (kg)
Cavity anchors	30	0,160	4,00	-	0,44
Staples wood fibre board	196	0,042	1,48	0,000336	2,66
Staples OSB3	196	0,042	1,48	0,000336	2,66
Screws gypsum board	98	0,035	4,20	0,000047	0,38
Screws horizontal wooden beam	32	0,060	4,20	0,000027	0,21
Threaded rod	4	0,060	6,00	0,000007	0,05

Furthermore, airtight tape is considered:

- At all seams between the OSB3 boards (8 seams x 2,44 m height); and
- At the top and bottom of the timber frame wall (2 x 3 m)

Table 8 summarizes the total amount of tape used.

Table 8. Air tight tape

Running meter (m)	Width (m)	Mass (kg/m)	Mass (kg)
25,52	0,06	0,0277	0,71

The results show that the impact of a wall including fasteners and tapes is higher than that of the wall excluding fasteners and tapes. This finding is quite logical as an additional amount of material is added, i.e. 6,40 kg of stainless steel and 0,71 kg airtight tape. By taking into account these secondary materials, the impact increases with 17,75%. This means that one fifth of the total impact of a typical timber frame wall is due to the fasteners and tapes. When only air tight tapes are included in the impact analysis, the impact increases with only 0,81%. This shows that the impact of air tight tape is negligible, whereas 16,94% of the total environmental impact results from the fasteners.

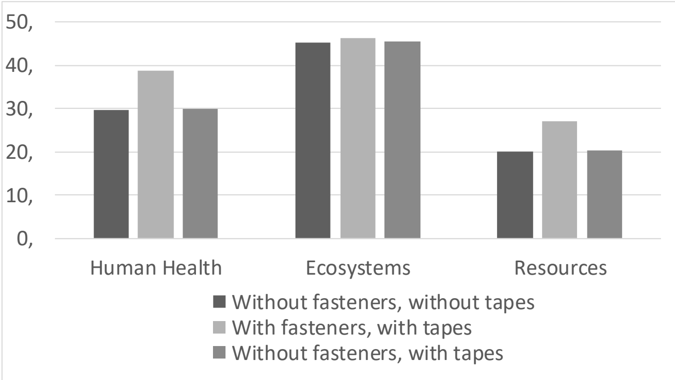

Figure 4. Impact of fasteners and air tight tapes

When analysing the impact categories, Figure 4 shows that the impact of fasteners and tapes on the Ecosystems category is negligible. The HH and Resources categories show the largest variation when including the fasteners.

Conclusions and future work

This paper discusses the environmental impact of timber frame walls. The results showed that the impact of timber frame walls can differ largely by the choice of constituting materials. For instance it was shown that choosing LVL studs results in a higher impact compared to I-joists. Naturally environmental impact is only one of the decision criteria in designing a sustainable construction. Furthermore, the analysis showed that external finishing materials can have a major environmental impact, especially when a brickwork façade is used. Also, it was demonstrated that fasteners have a significant contribution to the overall environmental impact.

In a next step the relative impact of fasteners should be assessed. Also the impact of alternative materials, such as plastic cavity anchors was not investigated in this study. Nevertheless, these fasteners could not only be favourable from a thermal point of view but also from an environmental point of view.

References

[1] *Tool to Optimise the Total Environmental impact of Materials* (TOTEM) 2018 Retrieved from www.totem-building.be
[2] Houtinfobois *Houtbouw in België 2015-2016* Retrieved from https://houtinfobois.be (in Dutch)
[3] Simapro version 8.4.0.0 PRé Consultants bv 2017
[4] Himpe E, Trappers L, Debacker W, Delghust M, Laverge L, Janssens A, Moens J and & Van Holm M 2013 Life cycle energy analysis of a zero-energy house *Building Research & Information* DOI:10.1080/09613218.2013.777329
[5] Royal Institution of Chartered Surveyors. Building Cost Information Service (BCIS) 2006 *Life expectancy of building components: suveryors' experiences of buildings in use: a practical guide*. Londen.
[6] De Roeck M and Vanroelen M 2018 *Analyse van de milieu-impact van houtskeletwanden* Master thesis (in Dutch)